

# HYPERONS IN EFFECTIVE CHIRAL QUARK MODELS

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Baryonic correlation functions are calculated within an effective chiral quark model motivated by the instanton liquid model of QCD. Using a flavour SU(3) symmetry for the local four-quark interaction and taking rotational zero modes for the quantization into account low-energy hadronic observables are in surprising agreement with experimental data.

## 1. INTRODUCTION

Today Quantum Chromodynamics (QCD) is believed to be the theory of the strong interaction, though it is up to now not possible to calculate mesonic and baryonic properties directly. But it is believed that the classical solutions of the Yang-Mills field equations describing semiclassical tunneling events play an important role for the QCD vacuum structure [1,2]. As a consequence of the zero mode solution of the Dirac equation in the presence of the instanton fields effective instanton-induced interactions between the quarks emerge [2]. Within the Instanton Liquid Model [3] it has been shown that the instanton dependent quark coupling constant provides - via a momentum dependent effective quark mass - a natural ultraviolet cutoff. However approximating the instanton dependent coupling by a constant one immediately obtains quark theories similar to the Nambu–Jona-Lasinio (NJL) model [4]

$$\mathcal{L}_{NJL} = \bar{q} (-i\gamma_\mu \partial_\mu + m) q + \frac{G}{2} \sum_{a=0}^8 \left[ (\bar{q} \lambda_a q)^2 + (\bar{q} \lambda_a i\gamma_5 q)^2 \right] \quad (1)$$

or in bosonized form to the chiral quark model of Diakonov and Petrov [3]. Though confinement is lost in these approximations, the maybe most important feature of QCD at low energies, i.e. spontaneous breaking of chiral symmetry, is maintained. This has

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the desired property that the lowest bound states out of two quarks, the pseudoscalar pions and kaons, appear as Goldstone bosons of the broken chiral symmetry. As a result important low-energy theorems such as PCAC and the Goldberger-Treiman relation are fulfilled. Within these effective quark theories and taking the large  $N_c$ -limit baryons emerge as solitons which are bound states of valence quarks coupled to the polarized Dirac sea of quarks and antiquarks. However, due to the underlying spherically symmetric hedgehog Ansatz for the chiral fields, these solitons are only mean-field solutions of time-independent field configurations carrying unit winding number.

## 2. HYPERON MASS SPLITTINGS

The starting point for the calculation of hadronic properties is the point-to-point correlation function  $\mathcal{C}_h(T) = \langle Q_h(\vec{x}_0, T/2) Q_h^\dagger(\vec{y}_0, -T/2) \rangle$ , which in the case of baryons is defined as the expectation value of the Ioffe currents

$$Q_B(\vec{x}_0, t) = \frac{1}{N_c!} \epsilon^{\alpha_1 \dots \alpha_{N_c}} \Gamma^{f_1 \dots f_{N_c}} q(x)_{f_1} \dots q(x)_{f_{N_c}} \quad (2)$$

where  $\Gamma^{f_1 \dots f_{N_c}}$  is a symmetric matrix in flavour and spin space and  $\epsilon^{\alpha_1 \dots \alpha_{N_c}}$  is a total antisymmetric tensor with respect to colour. Then for large Euclidean times  $T$  it reduces to [3]

$$\mathcal{C}_B(T) = \stackrel{T \rightarrow \infty}{\simeq} \Gamma^{f_1 \dots f_{N_c}} \Gamma^{g_1 \dots g_{N_c}} \Pi_{i=1}^{N_c} \left[ \phi_{n, f_i}(\vec{x}_0) \phi_{n, f_i}^\dagger(\vec{y}_0) \right] e^{-TE[B=1]} \quad (3)$$

where  $E[B=1]$  is the classical mean-field energy. In order to describe states with the quantum numbers of the physical baryons a semiclassical quantization scheme is adopted [5]. In this scheme the rotational zero-modes of the one-loop effective action are quantized assuming an approximate symmetry of flavour SU(3). Hyperon masses follow then again from the behaviour of the corresponding correlation functions in the large Euclidean time limit. As a result octet [8] and decuplet [10] representations for the hyperons appear as lowest possible states. Incorporation of symmetry breaking effects via strange and non-strange current quark masses yields then a nice explanation of physical spectra. To be precise hyperon splittings are determined within  $\pm 10 \text{ MeV}$  accuracy [6], whereas isospin splittings (especially n-p) are reproduced even within the experimental error bars [7]. One should stress that the parameters of the model are strictly fixed by requiring proper pion-decay and pion and kaon masses [6]. The constituent quark mass  $M$  is fixed in the baryon sector to be  $M \simeq 420 \text{ MeV}$  reproducing the hyperon spectra for  $m_s \simeq 180 \text{ MeV}$  (cf. Fig.1).

## 3. AXIAL CURRENTS

The recent EMC measurements on the nucleon structure functions suggested that only a small fraction of the proton spin (cf.  $g_A^{(0)}$  in Tab.1) is carried by the spins of quarks. This is in drastic contradiction to the naive quark model, in which the spins of  $N_c$  quarks are coupled to the known spin of the proton, and is therefore denoted as *spin crisis*. In the

present model it was shown [8] that the experimental number [9] for  $g_A^{(0)}$  can be explained with only a moderate contribution of the strange quarks ( $\Delta s$  in Tab.1). Furthermore the  $g_A^{(3)}$  and  $g_A^{(8)}$  are evaluated [10] (cf. Fig.2). The reason that the present values are in better agreement with experiment compared to former Skyrme model calculations is the next to leading order rotational correction in the  $1/N_c$ -expansion. These subleading terms are entirely due to the non-local structure of the effective action and cannot be obtained in local effective meson theories. However qualitatively they agree with recent large- $N_c$  estimates of Dashen and Manohar [11], which state that the coupling constant ratio of different hyperons obtains only corrections at the level of  $1/N_c^2$ . Numerically the nucleonic  $g_A^{(3)}$ , which was evaluated as  $\simeq 0.8$  in most of the chiral models, is now close to the experimental value because of the subleading  $1/N_c$  corrections (cf. Tab.1).

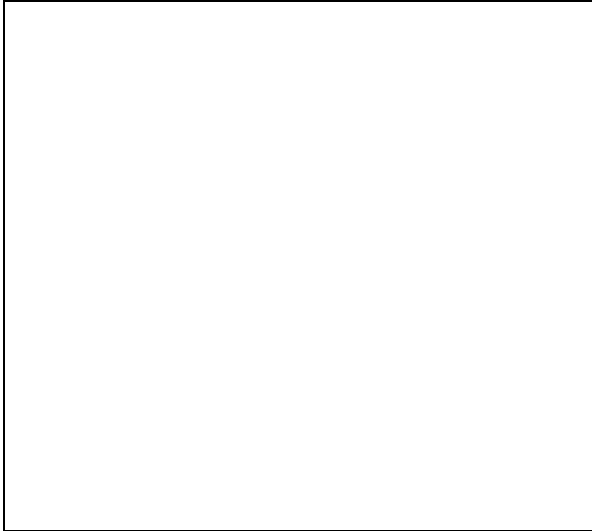


Figure 1. The deviations of the theoretical from the experimental mass for the [8] and [10] baryons as a function of  $m_s$ .

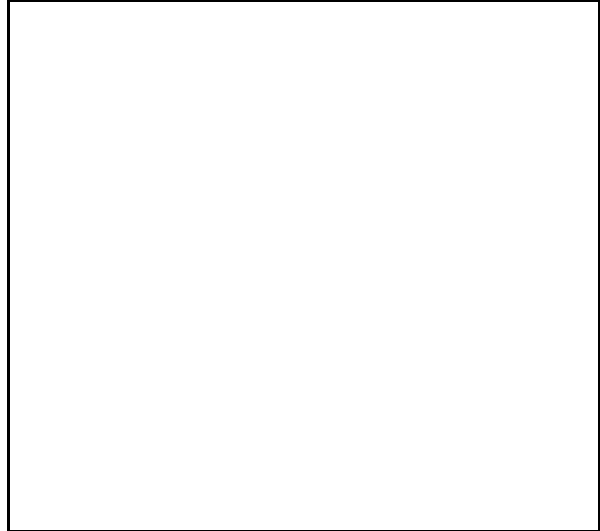


Figure 2. The axial vector coupling constants  $g_A^{(0)}$ ,  $g_A^{(3)}$  and  $g_A^{(8)}$  as a function of the constituent quark mass  $M$ .

#### 4. OTHER OBSERVABLES

In addition we considered strangeness corrections to the pion and kaon nucleon  $\sigma_{\pi N, KN}$ -terms, which are related to the formfactor of meson-nucleon scattering amplitudes at low  $q^2$ . Whereas  $\sigma_{\pi N}$  coincides with the experimental data [12] (cf. Tab.1),  $\sigma_{KN}$  is experimentally not yet known. Furthermore the Gottfried sum measured by NMC [13], which states that

$$S_G = \frac{1}{3} + \frac{2}{3} \int dx (\bar{u}_{sea}^p - \bar{d}_{sea}^p) = 0.240 \neq \frac{1}{3} \quad (4)$$

where  $\bar{q}_{sea}^p$  is the quark distribution function in the parton model within the proton (p), suggests a flavour asymmetric polarization of the up and down Dirac sea [14]. This effect

is qualitatively as well as quantitatively reproduced [15] (cf. Tab.1) within the present model.

Table 1

The axial vector coupling constants  $g_A^{(0)}$ ,  $g_A^{(3)}$ ,  $g_A^{(8)}$ , its strangeness contribution  $\Delta s$ , the pion and kaon-nucleon  $\sigma$ -terms, the Gottfried sum  $S_G$  and the strange content  $y = 2\bar{s}s/(\bar{u}u + \bar{d}d)$  of the nucleon for the NJL model compared with 'experimental' values.

	$g_A^{(0)}$	$g_A^{(3)}$	$g_A^{(8)}$	$\Delta s$	$\sigma_{\pi N}[\text{MeV}]$	$\sigma_{KN}[\text{MeV}]$	$S_G$	$y$
NJL	0.37	1.38	0.31	-0.05	45.2	499	0.234	0.457
exp	$0.31 \pm 0.07$	1.26	$0.35 \pm 0.04$	-0.10	$45 \pm 8$	?	$0.24 \pm 0.016$	?

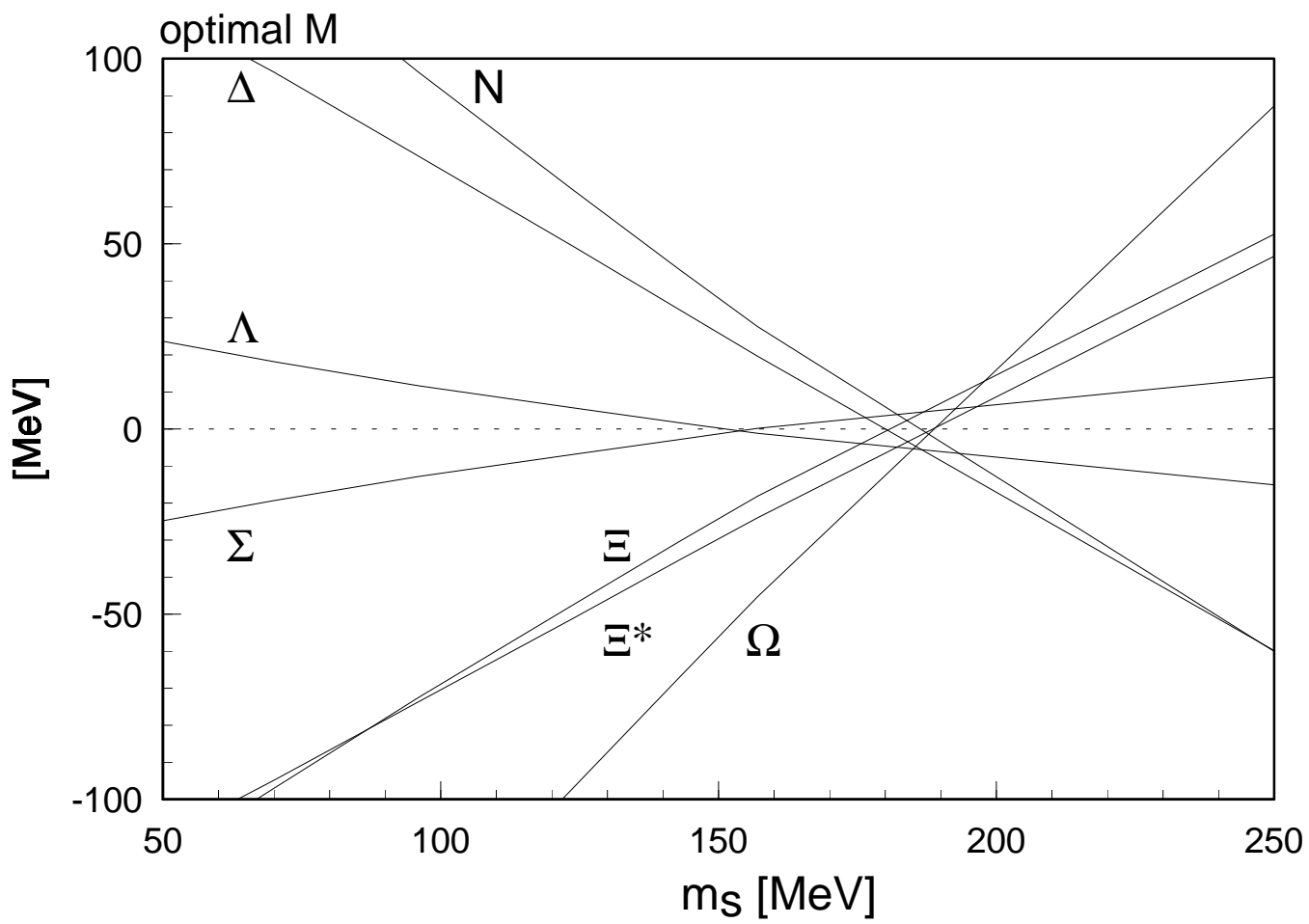
## 5. SUMMARY

Starting from an instanton liquid motivated effective quark interaction with SU(3) flavour symmetry it has been shown that low-energy baryonic observables, such as hyperon and isospin mass splittings,  $\sigma$ -terms and axial vector coupling constants, are in surprising agreement with experiment. Simultaneously the parameters of the theory are fixed by the masses and decay constants of the almost Goldstone bosons. This suggests that chiral symmetry and the spontaneous breaking of this symmetry is a key ingredient of an effective theory for the hadrons.

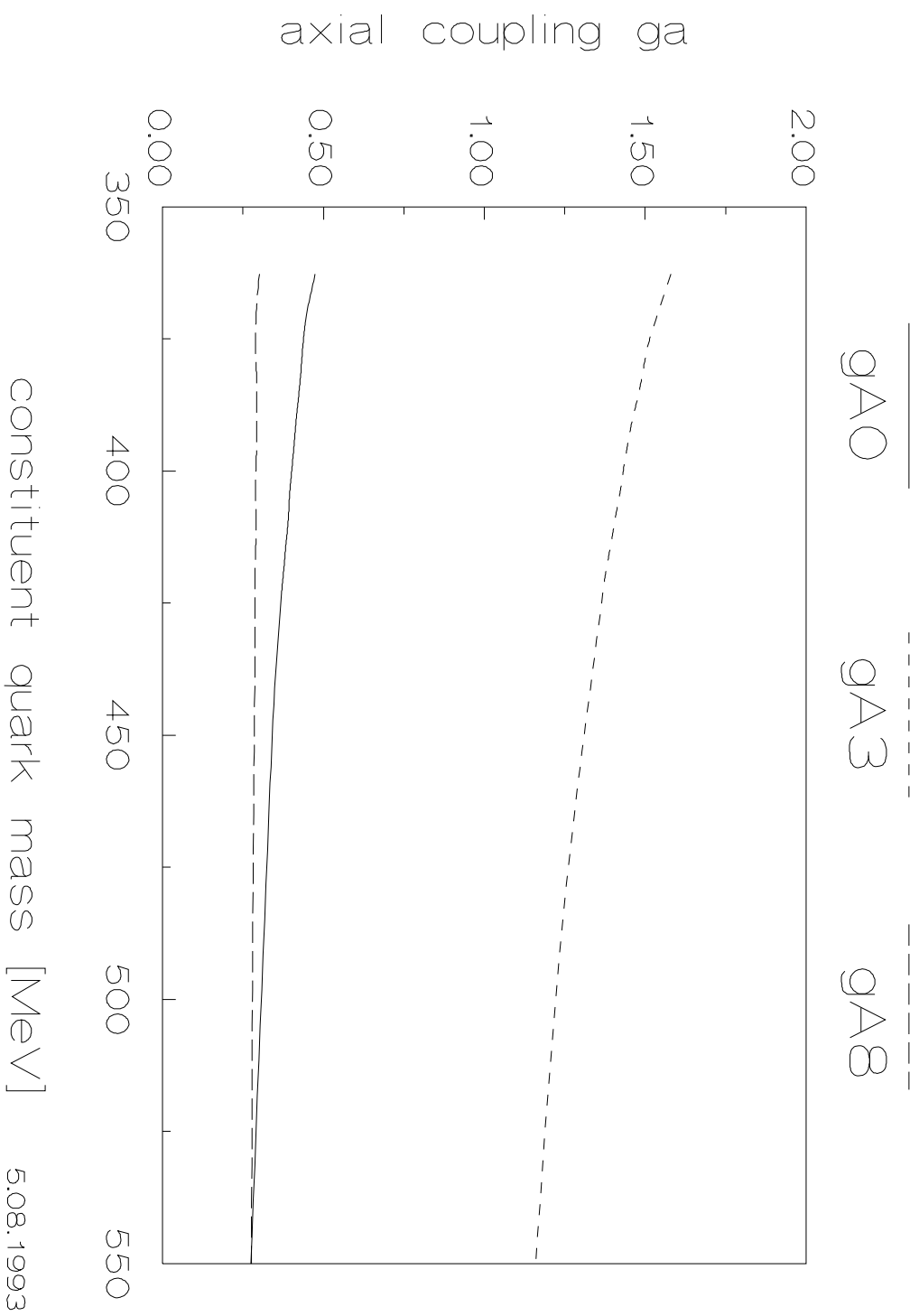
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- [1] A. Belavin, A. Polyakov, A. Schwartz, and Y. Tyupkin, Phys. Lett. B **59**, 85 (1975).
  - [2] G. t'Hooft, Phys. Rev. **D14**, 3432 (1976).
  - [3] D.Diakonov, V.Petrov, and P.Pobylitsa, Nucl. Phys. **B306**, 809 (1988).
  - [4] Y. Nambu and G. Jona-Lasinio, Phys. Rev. **122**, 345 (1961).
  - [5] G. Adkins, C. Nappi, and E. Witten, Nucl. Phys. **B228**, 552 (1983).
  - [6] A.Blotz *et al.*, Nucl. Phys. **A555**, 765 (1993).
  - [7] M. Praszalowics, A.Blotz, and K. Goeke, Phys. Rev. **D47**, 1127 (1993).
  - [8] A.Blotz, M. Polyakov, and K. Goeke, Phys. Lett. **B302**, 151 (1993).
  - [9] J. Ellis and M. Karliner, Determination of  $\alpha_s$  and the nucleon ..., , CERN-TH-7324/94, 1994.
  - [10] A.Blotz, M. Praszalowics, and K. Goeke, Phys. Lett. **B317**, 195 (1993).
  - [11] R. Dashen and A. Manohar,  $1/N_c$  Corrections to the Baryon Axial Currents in QCD, University of California at San Diego, UCSD/PTH 93-18, 1993.
  - [12] J. Gasser, H. Leutwyler, and M. Sainio, ETH preprint, 1990, bYTP-90/31, HU-TFT-90-56.
  - [13] NMC Collaboration P. Amaudruz *et al.*, Phys. Rev. Lett. **66**, 2712 (1991).
  - [14] M.Wakamatsu, Phys. Rev. **D46**, 3762 (1992).
  - [15] A. Blotz, Ph.D. thesis, Theoretical Physics II, Ruhr-University Bochum, D-44780 Bochum, 1994.

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*SU(3) Nambu–Jona–Lasinio model  
axial vector current*



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